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TAR PODS FROM THE YAZOO CLAY (UPPER EOCENE) AT CYNTHIA, MISSISSIPPI

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INTRODUCTION

Workers at the Miss-Lite Aggregate clay pit in Cynthia, Hinds County, central Mississippi, notified the Mississippi Bureau of Geology on two separate occasions during July of 1985 when their bulldozer uncovered tar pods in the Yazoo Clay. According to the workers, these pods covered an area of about five feet in diameter. The writer was able to observe in situ only the "roots" or tar-filled fissures of the second of these pods (Figures 1 and 2). These fissures were generally less than a quarter of an inch in diameter, oblique, and multidirectional. They tapered to a feather edge before terminating and penetrated only about one foot of substrate below the excavated surface. Remains of the main pod body consisted of four- to five-inch long, somewhat tabular, tar fragments with conchoidal fracture. This tar is relatively pure with the exception of some clay inclusions.

The clay-tar contact on some fragments indicates that the main pod body was lenticular and rested above a "root system" of tar-filled fissures. These fragments exhibit three distinct surface morphologies at the clay-tar boundary: (1) a basal surface that is smooth and slightly undulatory, (2) a lateral contact with lenticular lobes extending horizontally into the surrounding clay

Figure 1. Oblique view of in situ, interconnected, tar-filled fissures in the Yazoo Clay at the Miss-Lite clay pit in Cynthia, Hinds County, Mississippi. Photograph was taken on July 18, 1985.

Figure 2. Vertical view of in situ, tar-filled fissures in the Yazoo Clay. Photograph was taken on July 18, 1985.

(Figure 3), and (3) an upper and lateral contact with a lobate pillar structure (Figure 4). The host clay surrounding the tar pods is fossiliferous and of obvious marine origin. Dockery and Siesser (1984) placed the Yazoo Clay at the Cynthia pit in calcareous nannoplankton zone NP21 and date it as upper Eocene in age. The tar pods occur in the lower part of unit one as given in their report.

ORIGIN OF THE TAR PODS IN THE YAZOO CLAY

Each of the two tar pods excavated was a small, lenticular, fissure-fed body centered about a single focal point. The tar is apparently a residue of escaping hydrocarbons. Deposition of the tar in both fissures and lenticular pods demonstrates respectively both a compact, solid clay and a viscous clay matrix at the time of hydrocarbon movement. This varied compaction of the host clay indicates that tar deposition occurred syngenetically with sea-floor sedimentation during late Eocene time. Thus, the tar pods are a product of an Eocene, submarine "paleo-oil seep."

Figure 3. Tar fragment showing horizontal lenticular lobes penetrating the surrounding clay.

Figure 4. Tar fragment showing the lobate pillar morphology of the upper surface.

Hydrocarbons moving through vents on the upper Eocene, muddy, Yazoo shelf released their volatile components within the soft sea-floor sediments before escaping into the aqueous environment. Above the vents, a lenticular residue of tar built up in the viscous substrate and flowed laterally in a plastic state. This flow, though less viscous, slower, and on a miniature scale, was somewhat like that of a submarine lava flow as indicated by the lobate pillar surface morphology of the tar. Tar also accumulated at the top of fissures which fed the vents.

Tar generated by oil seepage is common in the Gulf of Mexico today. It is found as floating particles, as globular masses washed up on beaches, and as mat-like masses on the sea floor. Geyer and Sweet (1973)

illustrated an in situ submarine tar mass with a diameter of two feet in Laguna de Tamiahua, Mexico, that is similar in morphology to that postulated from tar fragments excavated from the Yazoo Clay. While many oil seeps and tar deposits in the Gulf are associated with known petroleum reserves, Wilson and others (1973) stated that most petroleum seepage is derived directly from the source rock. In this case, oil seeps are not necessarily indicators of underlying petroleum reservoirs.

The tar pods excavated from the Yazoo Clay were not associated with a fault plane, though small-scale faults (presumably due to slumping) do occur in the Cynthia clay pit. Geyer and Sweet (1973) stated that many present day oil seeps occur in areas where no faulting is evident. In a study of submarine gas seeps, Watkins and Worzel (1978) observed a pipelike wipeout on 3.5-kHz soundings beneath a prominent seep. This wipeout suggested a narrow cylindrical conduit for the upward movement of gas through the sedimentary sequence. Such a conduit is postulated here for the movement of hydrocarbons that penetrated the Yazoo Clay to form isolated tar deposits.

Oil seeps on the Yazoo marine shelf at Cynthia were probably produced by petroleum migrating from Upper Cretaceous strata of the Jackson Dome. Hydrocarbons either derived directly from their source beds or from a faulted Upper Cretaceous reservoir moved upward into aquifers (Cockfield and Moodys Branch formations) underlying the Yazoo Clay. Moving laterally within these aquifers, these hydrocarbons penetrated about three hundred feet of compact clay through narrow, cylindrical, pressure-induced fissure systems and were vented into the marine environment at isolated points.

The limited nature of the tar accumulation may be due to a limited amount of hydrocarbon seepage, the rarity of tar deposition at hydrocarbon seeps, or concurrent transport of tar deposits to the surface and subsequent deposition along the shoreline. Oil and gas fields in the area surrounding Cynthia include: (1) Jackson Gas Field, 6.4 miles to the south-southeast, producing gas from the Upper Cretaceous Jackson Gas Rock, (2) Flora Field, 10.0 miles to the north, producing oil from the Jackson Gas Rock, (3) Brownsville Field, 7.8 miles to the west-northwest and above the Brownsville Salt Dome, producing oil from the Tertiary Wilcox Formation, and (4) Bolton Field, 11.0 miles to the west-southwest, producing oil from various Lower Cretaceous formations. Cynthia is situated on the northern flank of the Jackson Dome, making this structure the most likely source of hydrocarbons. If a faulted reservoir were responsible for the "paleo-oil seeps" at Cynthia, it is possible that this reservoir was/is closer to the site than the oil and gas fields mentioned. Either this reservoir has yet to be discovered or its reserves were vented out into the late Eocene ocean that once covered the region.

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PALEOECOLOGY OF SOME CLASSIC TERTIARY LOCALITIES IN THE AQUITAINE AND PARIS BASINS OF FRANCE

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INTRODUCTION

The Aquitaine and Paris basins of France and the northern Gulf Basin of the southeastern United States contain excellent Paleogene marine sequences. Paleogene stages or groups within these basins have been used as standards for worldwide stratigraphic correlations for over one hundred years. In the northern Gulf, the Eocene and Oligocene marine sections are particularly well preserved along the eastern flank of the Mississippi Embayment in Mississippi and southwestern Alabama. These marine sections can be closely correlated with those of the Aquitaine and Paris basins by means of calcareous nannoplankton as demonstrated by Pujol (1979), Siesser and Dockery (1985), and others.

Comparative studies of the northern Gulf and French Paleogene strata show parallel development of many taxa and similarities in the paleoecology of benthic faunas. Such studies also demonstrate cyclical histories of sea level fluctuation in widely separated basins as well as the tectonic development of these basins. Tectonic processes were more pronounced in the Aquitaine Basin, which was associated with the Pyrenean Orogeny during the Eocene Epoch. Reconstructions of fossil communities from the diverse Paleogene sedimentary facies of the Aquitaine and Paris basins provide useful models for paleoecological studies of related environments in Mississippi's Eocene and Oligocene sequence.

EOCENE OF THE AQUITAINE BASIN (BEARN BASIN - PAU AREA)

The Aquitaine Basin is a coastal basin that contains three east-west trending structural zones (Pomerol, 1973, 1982): (1) a northern zone, (2) a median zone, and (3) the Pre-Pyrenean Trench (an extension of the Aturian Gulf). This complex basin is not well understood despite a recurrence of interest in the subject within the geologic community. Tertiary invertebrate faunas within the Aquitaine Basin show many interesting relationships to those of the North American Gulf realm. In this paper, data derived from studies of invertebrate faunal assemblages are analyzed to determine the fossil communities and paleoecology for several classic Eocene and Oligocene localities in the Bearn and Adour subbasins of the Aquitaine Basin. These localities are the same as those studied by Siesser and Dockery (1985) so that the fossil communities can be placed in the proper biostratigraphic framework.

The Paleogene localities studied in the Bearn Basin of the Pau area consist of the Acot and "Tuilerie" outcrops. A major tectonic feature that influenced the depositional history of these outcrops was the Pre-Pyrenean Trench. This trench extended eastward from the Atlantic as far as the Corbieres in the late Paleocene to early Eocene but retreated westward to the vicinity of Ossun (between Pau and Tarbes) in the late early Eocene. North to south barriers associated with diapiric

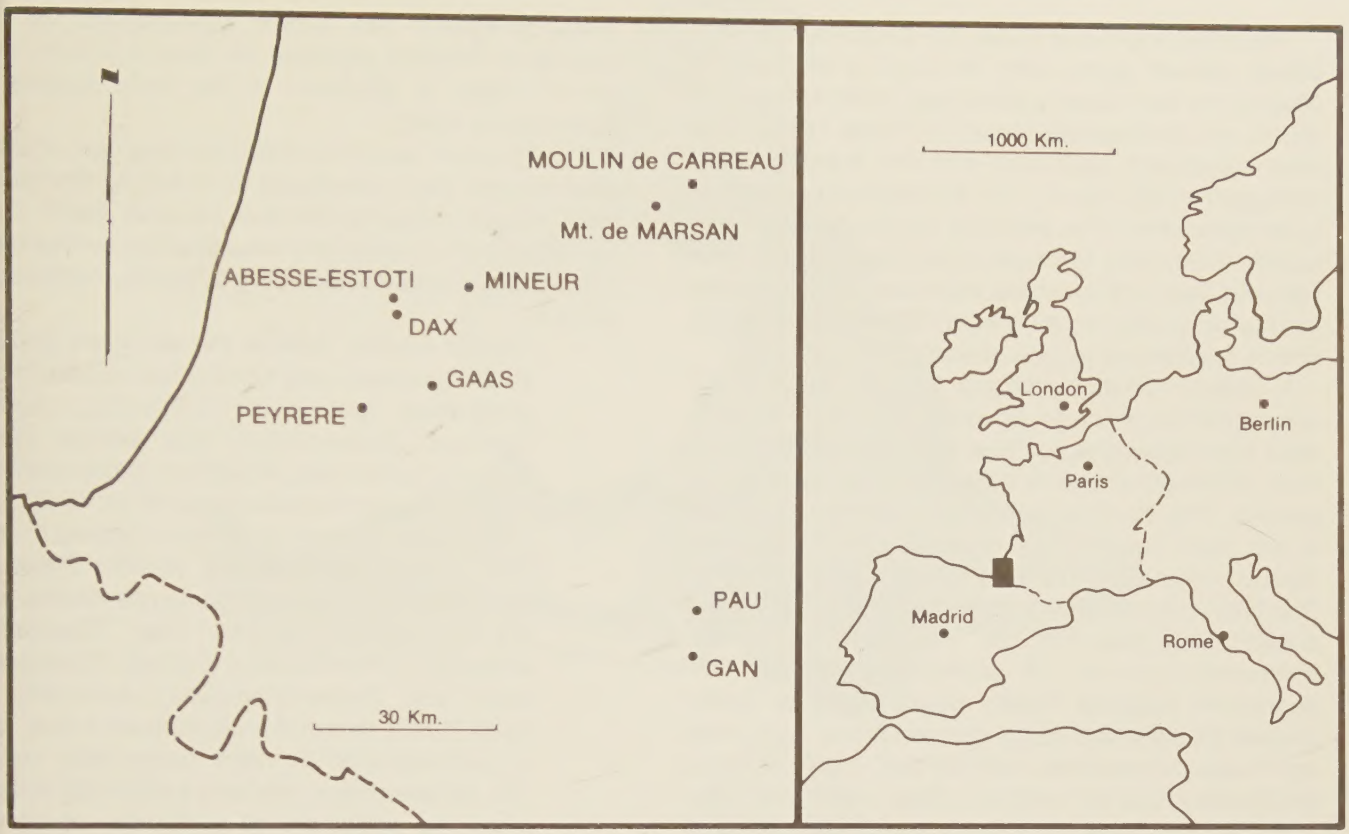

Figure 1. Tertiary localities in the Aquitaine Basin, southwestern France.

salt movements (Pomerol, 1973) divided this trench into a series of steps that hindered the transport of detritus toward the Altantic. The Acot locality marks the transition from the continental shelf (represented by the "Tuilerie" locality) to the deep axial zone. Analyses of biofacies in the area of Gan (near Pau) are complex because of the gradual ecological transition of taxa between the fossil communities represented in the Acot and "Tuilerie" outcrops. These outcrops have many genera in common. The occurrences of some of these genera, though characteristic, are reported here for the first time.

Acot parish of Gan

The outcrop at Acot contains a three-meter exposure of a compact, dark gray, silty clay lithofacies having an unvarying composition. Fossils are disseminated sparsely throughout the section and in irregularly dispersed small pockets occurring from one to one and one half meters above the base. Color seems to provide a convenient clue as to the origin of fossils at Acot. Fossils having a gray to black color include "Nipadites" (palm tree fruit) and many Archeogastropoda indicative of rocky shores. These fossils were transported from coastal environments before their deposition at Acot. Shells having an ivory color comprise the fossil community; however, only those fossils associated with articulated valves of the dominant bivalve *Saturnia* are considered to be in situ. This community contains:

1. Deposit feeders including the bivalves *Nucula* (s.l.), *Nucula (Lamellinucula), Saturnia, Portlandia,* and *Lithoradia,* the gastropods *Calliotropis, Argyropeza, Tibia* (s.s.)?, and *Tibia* (cf. *Sulcogladius*), and small echinoids.
2. Suspension feeders including the bivalves *Propeamussium* (*Parvamussium*), *Limatula,* and *Bathyarca,* and some rare brachiopods and solitary corals.
3. Scavengers and predators including the gastropods *Bonnellitia,* Turridae (20 small species), Olividae, *Ringicula, Cylichna,* with rare occurrences of *Semicassis,* cf. *Muricopsis,* Cymatiidae, Mitridae, and others, the plentiful scaphopods *Dentalium* (*Compressidens*), *Cadulus* (s.s.), *Cadulus* (*Gadila*), *Entalina,* and the carnivorous bivalves *Cuspidaria, Verticordia,* and cf. *Haliris.* Also included in the Acot paleocommunity are rare occurrences of parasitic gastropods.

The autecologic data known for the previously mentioned genera agree with lithologic indications in placing the Acot fossil assemblage in the terrigenous mud-shelf communities group of Peres (1982). The marine sediment associated with this faunal group is composed of silt and clay with rare admixtures of sand. Upon deposition, this sediment produces a relatively mobile (fluid) mud. Because of the high sedimentation rate and very soft substrate consistency, hard bodies tend to be quickly buried (Peres, 1982). Consequently, sessile species are largely absent.

In spite of a stratigraphic gap, the Acot fauna closely resembles that of the St.-Etienne d'Orthe upper Oligocene fossil assemblage. These two assemblages show many strikingly similar or substitutive genera and even species. The St.-Etienne d'Orthe (and consequently Acot) fossil assemblage resembles the Hungarian Egerian *Hinia-Cadulus* communities of Baldi (1973). The fossil communities of Baldi (1973) agree with living communities described by Hartman (1963) from submarine canyons off southern California. This agreement supports Baldi's communities as useful models for paleoecological interpretations. Both living and fossil communities indicate that the Acot fauna developed along the unlighted deep circalittoral zone of the Aturian Sea and probably penetrated the top of the bathyal zone. Autecologic data on *Argyropeza* (Houbrick, 1980) place the bathymetric range of this fauna at 150 to 300 meters.

The "Tuilerie" parish of Gan

The west slope of the classical "Tuilerie" outcrop, near Gan's railway station, exposed only a part of the 16-meter section cited by Dolin and Dolin (1983). This section contained large foraminifers and consisted of: (1) a basal silty clay with a splintery breakage, (2) a middle dark and blue-gray silty clay with conchoidal breakage, and (3) an upper yellowish-brown silty clay. These strata contain a thanatocoenosis comprised of allochthonous elements of heterogenous origins and autochthonous elements of the fossil community. Notable proofs of an indigenous origin within the fossil community include the suspension-feeding endobiontic annelids (in situ) of the *"Diptrupa" subgranulosa* group (20 cm to 30 cm in length), the presence of all ontogenic development stages of the gastropods, articulated shells of the epibiontic bivalves *Chlamys rouaulti, Spondylus ogormani, Spondylus paucispinosus* (as figured by Cossmann, 1923, pl. 2, fig. 25), and the endobiontic bivalves *Pinna pyrenaica* (ibid., text figs. 2-4), *Cardium* (*Trachycardium*) *gigas* (ibid., text fig. 1), *Crassatella ogormani* (ibid., pl. 2, fig. 5), the articulated crabs, and corroborating evidence of predation such as malacophageous fish and/or cephalopods on the gastropod *Gisortia gigantea* as cited by Dolin and Dolin (1983). A specimen of the latter species is illustrated in Plate 1.

The "Tuilerie" section contains a succession of fossil assemblages that correspond to changing lithofacies and indicate a regular decrease in water depth. Collectively the distribution of the successive communities' characteristic species according to feeding habits is as follows.

1. Deposit feeders include the abundant gastropods *Sigmesalia* and Cerithiidae and the more uncommon gastropods *Chedevillia, Dientomochilus* (*Ectinochilus*), and several allied genera or subgenera, *Xenophora* (many species), and the bivalve *Nipponulimopsis* (or *Cratis*).
2. Suspension feeders other than those previous cited include the epibiontic bivalves *Chlamys, Spondylus, Plicatula,* and *Dimya deshayesi,* and the endobiontic bivalves *Pitar* (*Calpitaria*), *Aphrodina, Petalocardia, Corbula* (*Caryocorbula*), and *Tellina* (*Peronidia*). According to Baldi (1973), these bivalves indicate a slow rate of sedimentation in calm, oxygenated water. The sedimentation rate was sufficiently slow to allow the settlement of a diversity of sessile suspension feeders including the worm *Serpula,* the gastropod *Vermetus,* the stalked crinoid *Conocrinus,* the bryozoan *Lunulites,* and the solitary corals *Odoncyatus* and cf. *Trochocyatus.*
3. Scavengers and/or predators include the gastropods Globulariidae, *Hexaplex, Pterynotus, Typhis* (*Siphonochelus*), Cymatiidae, Fasciolariidae, Olividae, *Fusimitra,* Volutidae, *Hemiconus,* Turridae, and Pyramidellidae, and the scaphopods *Dentalium* (cf. *Rhabdus*) and *Entalina.* Some parasitic gastropods are also present. Other less frequent gastropods include several species of Ovulidae (Dolin and Dolin, 1983), a family which is presently a symbiot of the alcyonarian and gorgonian corals, the echinoid predators *Cassidaria* and *Semicassis,* the fragile *Tudicla,* and the curious *Austropharpa?* (*Pseudoscapha*). Least in abundance are the larger gastropods *Amaurellina* (*Pachycrommium*), *Tibia* (*Ampogladius*), *Vicetia, Clavilithes,* and others. These mollusks by their biomass indicate the high productivity of the biotope.

The high population density and specific diversity of pteropods at "Tuilerie" suggest the long term presence of vertical currents (upwellings) rich in nutrients (fide Baldi, 1973). These currents are important to benthic as well as planktic organisms.

"Tuilerie" fossil assemblages are related to the silty

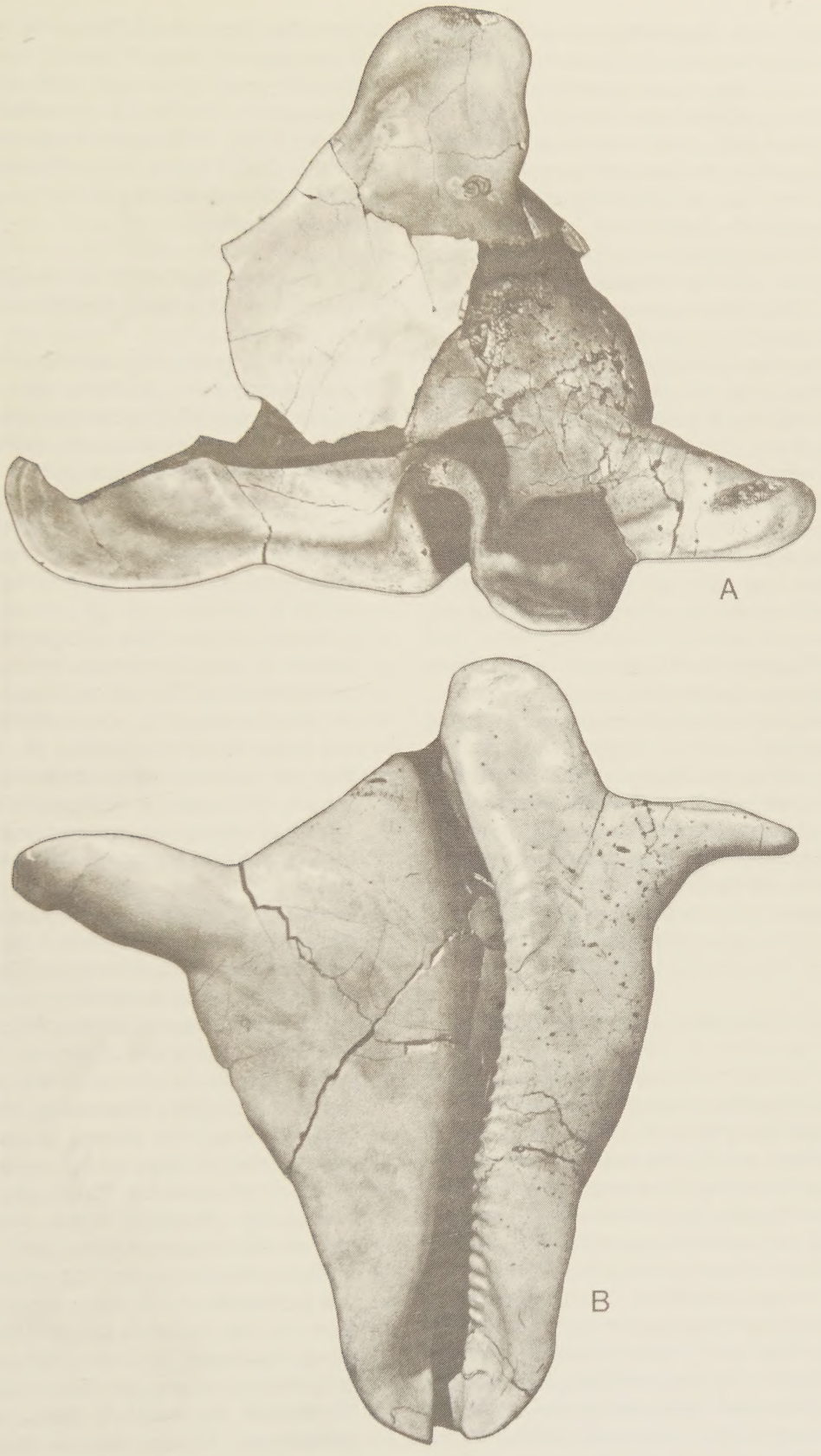

Plate 1. Apical (A) and apertural (B) views of *Gisortia gigantea* (Munster, 1828) from "Tuilerie", Gan, France. Length 177.4 mm, width 107.4 mm. Apical view shows breakage due to fish or cephalopod predation.

or muddy detrital sand assemblage group of Peres (1982). Of the many fossil assemblages that might be included in this assemblage group (over 100, fide Peres, 1982), the "Tuilerie" assemblages seem to have the closest relationship with the *Alveinus-Corbula* and *Nucula-Hipponix*-solitary coral assemblages of Elder and Hansen (1981) from the Moodys Branch Formation (upper Eocene) in Mississippi and Louisiana. The Moodys Branch fauna, as described in part by Dockery (1977, 1980) and paleoecologically reviewed by Shiebout et al. (1982), shows many convergences with the "Tuilerie" fauna at the generic level (i.e. *Fusimitra*). The "Tuilerie" fossil assemblages also display affinities with deeper infralittoral and circalittoral communities and particularly with the *Pitar beyrichi* and *Flabellipecten-Odoncyathus* communities of Baldi (1973), which lived in depths ranging from 30 to 120 meters.

Stalked crinoids, which presently live in deep water environments, permit reliable estimates for bathymetric ranges of respective paleobiotopes. Roux and Plaziat (1978) discussed and gave an "actualistic" interpretation of stalked crinoids from some lower Cenozoic Pyrenean outcrops without including Acot and "Tuilerie". The "Tuilerie" locality contains a significant number of columnal pieces of *Conocrinus* species, indicating a calm neritic platform environment ranging between 100 and 150 meters in depth (fide Roux and Plaziat). However, Roux and Montenat (1977) observed that *Conocrinus* and related crinoids have the propensity in active tectonic zones (such as was the case for the "Tuilerie" deposits, which were contemporaneous with the rising of the Pyrenees) to inhabit shallower waters. The stalked crinoid *Conocrinus* at "Tuilerie" was probably at the uppermost limit of its range in a tectonic zone.

Stratigraphy of the Acot and "Tuilerie" Outcrops

The "Cuisian" of Gan consists of a 800-meter thick sequence of sandy or silty clays that are nonfossiliferous in the greater part. Schaub (1981) in a study of benthic foraminifers placed the entire section in the *Nummulites planulatus* or *Alveolina oblonga* zone (P 8) of the lower Cuisian (upper Ypresian) and placed the Acot outcrop as older than that at "Tuilerie". Siesser and Dockery (1985) placed samples from "Tuilerie" as NP 14 (= P 9 in part) based on the occurrence of *Rhabdosphaera inflata.* This placement gives a younger age (later upper Ypresian to lower Lutetian) than that assigned by Schaub and classical European authors, and confirms the writers' conclusions derived from a study of the Ovulidae (Dolin and Dolin, 1983). In this study, some of the "Tuilerie" Ovulidae were found to be conspecific with species from the Meganos Formation (middle Eocene) of California. Also, the Triviacea-Cypraeacea of the "Tuilerie" malacofauna are more evolutionarily advanced and strictly different from those of the Cuisian s.s. of the Paris Basin (NP 12, fide Aubry, 1983). This fauna is more closely related to the early Lutetian fauna of San Giovanni Ilarione, Italy, and Chaumont-en-Vexin (NP 14 fide Aubry, 1983) and Parnes, France.

OLIGOCENE OF EUROPE: PALEOCLIMATIC SETTING

The European Oligocene is divided into two stages: the Stampian (= upper Tongrian and Rupelian) and the upper Oligocene (Chattian). Cavelier (1979) placed the Eocene-Oligocene boundary between P 17 and P 18 and between NP 21 and NP 22 at the base of the Stampian. According to Cavelier and Pomerol (1976) and Pomerol (1978), the lower Oligocene or Stampian is P 18 to P 20/N 1 and NP 22 - NP 23, and the upper Oligocene or Chattian (s.l.) is P 20/N 1 to P 22/N 3 and NP 24 to NP 25.

Paleontologists have recognized for many years the existence of two provinces in the Tertiary of Europe: a "northern" or "boreal" province and a "mesogean" or "Mediterranean" province. Hall (1964) demonstrated the present-day relationship of molluscan provinces and shallow water marine climates. This work provides a basis for analyzing European Oligocene molluscan faunas to distinguish marine climate zones during this period. Thus, in the lower Oligocene of the Aquitaine Basin (along with other basins in Italy, Yugoslavia, Rumania, and Armenia) there are very rich mesogean faunas (Cavelier, 1979) containing *Turbo* (including various subgenera), *Cerithium* (*Gourmya*), *Campanile,* Cypraeidae, *Globularia, Strombus, Oostrombus, Cymathium, Cassis, Melongena, Harpa, Vasum, Chlamys arcuatus, Crassatella, Discors, Nemocardium,* and others. This fauna is identical with the Indian Oligocene fauna described by Vredenburg (1925, 1928) and characterizes the inner tropical zone. During the same period, most of these genera are unknown or very rare in the Paris Basin and Mainz Basin (Germany) and are totally unknown in the Belgian Basin, which represents the fauna of the North Sea Basin.

The molluscan faunas of the Paris and Mainz basins are indicative of the outer tropical zone, while the fauna of the lower Rupelian of Belgium (Sables de Berg) indicates a warm temperate climate. The presence of many genera in the lower Oligocene (Stampian) of the Paris Basin such as *Jujubinus, Omalogyra, Rissoa, Bittium, Potamides, Aporrhais, Glycymeris, Corbula* (*Varicorbula*), and *Lentidium,* which are very common in the Lusitanian (Mediter-

ranean) Province, along with paleosynecologic analysis (Gitton et al., in press) indicate that the modern Mediterranean Province began in the early Oligocene.

The upper Oligocene (Chattian) mollusks of the North Sea Basin as revised by Janssen (1978, 1979) and of the Paratethys (Central Europe, Egerian) contain certain tropical genera such as *Orbitestella, Protoma, Ficus, Morum, Lyria, Oliva, Perrona,* and others, which are indicative of the outer tropical zone. At the same period typical Oligocene tropical species appear in the upper Egerian of Hungary (upper Oligocene according to Baldi, 1973) including *Trisidos schafarzcki, Crassatella carcarensis, Globularia (Cernina) compressa, Tibia dentata, Tibia neuvillei, Melongena basilica, Euthriofusus burdigalensis,* and *Athleta rarispina.* The distribution of these taxa shows a broad expansion of the tropical mesogean (Mediterranean) province before the close of the Oligocene Epoch. This expansion is a precursor to an extension of the province into the Paratethys domain in the Miocene Epoch.

The previously mentioned Tertiary climatic zones of Europe are supported by several lines of biological evidence. Data provided by reef corals indicate that the northern limit at which coral reefs were prolific during the lower Oligocene (Cavelier, 1979) and probably also during the upper Oligocene was approximately at the present day 45° N latitude (north of the Aquitaine Basin). This limit is almost identical with the northern limit of the molluscan inner tropical zone.

Lower Oligocene (Stampian) of Adour Basin

The world-famous Gaas marls are well known for their abundant and excellently preserved marine fauna. As a matter of fact, this faunal assemblage is the richest and best preserved assemblage of the European mesogean lower Oligocene. Several studies have been made on the Gaas fauna including the benthic foraminifers (Poignant, 1967), corals (Chevalier, 1956), and mollusks (Vergneau-Saubade, 1967).

At the Lagouarde locality, the series begins with marls that contain the branched corals *Stylophora, Acropora, Dictyarea,* and others, some small coral patches, and various mollusks including the bivalves *Lima, Corbula (Caryocorbula),* and *Cardium,* and the gastropods *Lucapinella, Collonia, Homalopoma, Orbitestella, Deshayesia,* and Bullidae. Intercalated with the coral-rich marls are beds containing abundant gastropods of the family Globulariidae including *Ampullinopsis crassatina, Crommium angustatum,* and *Deshayesia parisiensis.* The species *Lucapinella clypeata* of the subfamily Diodoriinae is also present. These sediments, which probably reach a thickness of about 10 meters, were deposited in very tranquil conditions within the littoral environment. Laterally at Espibos, they grade into a blue marl with pieces of lignitized wood and a brackish water fauna.

Overlying the branched coral marls at Lagouarde is the famous *Oostrombus auriculatus* layer, which yields the major part of fossils from Gaas. The thickness of this layer is 70 cm at Lagouarde and 40 cm at Espibos. It is a sandy, yellowish or steel-blue marl containing many worn, current-rolled shells. This layer contains an accumulation of mollusks, bryozoans, and corals from different biocoenoses indicating current transport. However, the most common forms are well preserved and were derived from coral reef environments near the shoreline.

The uppermost unit contains an abundance of the foraminifer *Nummulites intermedius.* At Lagouarde, this unit consists of sandy marls, which are locally indurated. These marls grade into sandy limestones at Espibos.

The molluscan assemblage of the Gaas strata is typical of the lower Oligocene (Stampian) with characteristic species associated with the tropical European mesogean province including *Oostrombus auriculatus, Strombus radix, Ampullinopsis crassatina,* and *Campanile charpentieri.* A small part of the Gaas fauna invaded the Paris Basin in the upper Stampian (Sables of Pierrefitte). It is possible that the tropical fauna of Gaas corresponds to the "hot phase" of the upper Stampian of the Paris Basin. In a study of the genus *Hammatocythere,* Ducasse and Rousselle (1979) distinguished four ostracod biozones in the Stampian of the Aquitaine Basin. The Gaas strata at Lagouarde and Espibos are situated in the uppermost biozone.

Upper Oligocene (Chattian) of the Adour Basin

The lower - upper Oligocene boundary coincides reasonably well with an important lowstand in the eustatic sea-level curve of Vail et al. (1977). In France, the upper Stampian was a period of regression with the sea retreating from the Paris and Armorican basins and from the northern part of the Aquitaine Basin. In the Adour Basin (southern part of the Aquitaine Basin), Kiener (1973) recognized an important erosional phase during the Stampian in which the Saubrigues Paleocanyon was downcut. This paleocanyon was invaded by the sea in the late Oligocene due to both subsidence and eustatic sea-level rise and contains the only marine upper Oligocene deposits known in France. Presently the Saubrigues Paleocanyon is filled with a few hundred meters of upper Oligocene and lower Miocene (Aquitanian, Burdigalian) sediments. The remains of this canyon form the present day "le Gouf de Capbreton" (Capbreton Canyon, Gascogna Gulf).

The discovery of upper Oligocene marine strata within the Saubrigues Paleocanyon is attributed to Raulin (1890). The position of the "Faluns bleus" of Raulin (blue shelly marls) has been a subject of discussion for many years. These deposits begin with the sandy marls of La Peyrere near Peyrehorade, which contain the beautiful lepidocyclinids (Cahuzac, 1980) *Miogypsinoides ubaghsi* and *Miogypsinoides complanatus,* 30 species of corals (Chevalier, 1963), and about 400 species of mollusks. According to Chevalier, this community lived in the sublittoral zone between 50 meters and 100 meters in depth and corresponds to the muddy detrital assemblage of Peres (1982). Strata of the same age near La Peyrere (Tauziede and Haulon) have yielded planktic foraminifers and calcareous nannoplankton of the N 3 - N 4 (part) Zone and NP 25 Zone.

Farther west, the blue-gray marls of St.-Etienne d'Orthe are also upper Oligocene in age but are younger than the La Peyrere deposits. These marls were deposited probably in a bathyal environment on the upper part of the continental slope and contain a fossil community similar to the Hungarian upper Oligocene (Egerian) *Hinia-Cadulus* community of Baldi (1973). Mollusks of the St.-Etienne d'Orthe community consist of suspension feeders *Corbula* (*Varicorbula*), predators of the families Volutidae, Turridae, Ringiculidae, and Dentaliidae, scavengers *Hinia,* deposit-feeders Nuculidae, *Tibia neuvillei* and the characteristic endemic aporrhaid species *Triacontium mirandus,* and the parasitic family Pyramidellidae. Other mollusks include the deep-water archeogastropod family Seguenziidae, the Rissoidae species *Profundialvania peyreirensis,* and the epibiontic bivalve *Amussium* (*Propeamussium*) *duodecimlamellatum.*

Fossiliferous marine upper Oligocene strata in the coastal region of the Adour Basin occur at Escornebeou, Saint-Paul-les-Dax (Abbesses and Estoti localities), and Pontonx (Mineur locality). The St.-Geours de Maremne (Escornebeou) locality is a series of old marl pits 15 kilometers southwest of Dax. The mollusks of this locality are known only by the Pectinidae, which Dollfus (1917) concluded were of upper Oligocene age. A study of the calcareous nannoplankton by Muller (*in* G.F.R.N., 1974) placed the Escornebeou deposits in the *Spherolithus ciperoensis* Zone (NP 25). The biotope at Escornebeou was characterized by poorly oxygenated water above a muddy substrate.

Upper Oligocene fossils in the vicinity of Dax were first studied by Grateloup in 1820. In 1847, Grateloup published his monograph "Conchyliologie fossile des terrains tertiaires du bassin de l'Adour," which included 48 plates of gastropods.

Outcrops in the parish of Saint-Paul-les-Dax contain fringe reef coral facies, which are 2 to 3 meters thick at Abbesses and only 20 centimeters thick at Estoti. The molluscan assemblages also differ between these two localities in that they are not exactly contemporaneous but close together. At Estoti the basal section consists of sandy limestone with reef corals and a molluscan fauna of *Tibia dentata, Cassis aquensis, Keepingia praecedens* (all three species are unknown at Abbesses), an abundance of the family Eulimidae (parasitic on holothurians), species of *Alvania* and Cerithiopsidae (which live in association with sponges), and well preserved specimens of *Patella* n. sp. (unknown at Abbesses) and *Siphonaria* (which indicate the proximity of the mediolittoral zone). This coral facies is overlain by a sandy limestone that is locally indurated and contains small abraded (rolled) fossils including fragments of *Donax.* The thanatocoenosis of this facies indicates sedimentation on the lower beach environment.

The basal strata at Abbesses contain two easily distinguishable coral horizons that vary laterally. In the first horizon, the corals are in situ and constitute coral patches. Lateral spaces between the coral patches contain a fauna dominated by benthic foraminifers but also containing the browsing gastropods *Alaba, Tricolia,* and *Rissoina* (genera that are rare or unknown at Estoti), and a small species of the sessile bivalve *Pteria.* This assemblage indicates the presence of a well developed flora of metaphytes. In the second coral horizon, many fossils are abraded (rolled), and the positions of corals and bivalves (convex face up) and the presence of pebbles indicate a different hydrodynamic regime of moderate to high energy.

Overlying the second coral horizon is a sandy limestone devoid of corals. This bed was deposited in more tranquil conditions than that of the previous environments and contains bivalves with both valves present. Weathering of this bed below its Quaternary overburden has leached much of its fossil content. On the whole, the molluscan assemblage of Abbesses is characterized by: *Alaba, Tricolia, Rissoina* (several subgenera), *Erato, Globularia* (*Cernina*), *Athleta rarispina,* and *Melongena basilica.* These mollusks are rare or unknown at Estoti.

According to Saubade and Cahuzac (1978), the mollusks of Abbesses-Estoti indicate an upper Oligocene age. Mollusks of this fauna that are typical of the upper Oligocene of the European mesogean province include *Trisidos* (upper Oligocene in Italy and Hungary), *Globularia* (*Cernina*) *compressa, Sphaerocypraea oligovata, Melongena basilica,* and *Volutilithes subelegans.* The *Melongena* lineage is a good example of morphological evolution during the upper Oligocene

and lower Miocene in western Europe and probably also in eastern America where similar species are known.

Molluscan species which are otherwise regarded by the writers as typically Miocene also occur at Estoti and Abbesses, including *Ficus burdigalensis, Trona leporina, Tibia dentata, Homalocantha pauli, "Tudicla" rusticula, Euthriofusus burdigalensis,* and *Subula plicaria.* Likewise some typical lower Oligocene (Stampian) taxa are present including *Rhinoclavis submelanoides, Ataxocerithium pellati, Globularia,* and *Keepingia.* The Abbesses-Estoti molluscan fauna contains a notably larger number of Miocene forms than do other upper Oligocene strata in the Adour Basin. Therefore it probably represents the upper part of the Adour Basin upper Oligocene. The same results were deduced from a study of *Miogypsinoides* by Drooger and Freudenthal (1964). According to Cahuzac (1980), it may be concluded that the strata of Abbesses-Estoti correspond to the upper part of the *Globigerina ciperoensis* Zone and the lower part of the N 4 Zone (after the time scale of Hardenbol and Berggren, 1978, p. 218). The age of this sequence according to the time scale of Pomerol (1978) can be estimated at 22-24 MA.

At Pontonx (Mineur) the paleoecological succession in the upper part of the sequence can be briefly summarized as follows. The base of the outcrop is a sandy, gray to yellow marl with fossiliferous lenses. This unit contains the bivalves Lucinidae, *Donax,* and *Lentidium* n. sp. along with other shells, often abraded (rolled), from different biotopes including *Nerita* and the family Auriculidae. This assemblage corresponds to the present-day biocoenosis of the upper clean sand assemblages of Peres (1982), which may be observed on the lower beaches of shores worldwide. Overlying the first bed at an interval from 40 cm to 50 cm from the base of the outcrop is a black clay containing numerous *Isognomon,* oysters, *Teredo* tubes, *Calyptraea, Terebralia,* and many pieces of lignitized wood, some of which have barnacles attached. These fossils suggest the presence of mangrove swamps. Above this clay are sandy blue marls with a progressive development of sandstone pebbles upward within the unit. This unit indicates the formation of a lagoon and a return to a moderate to high energy flow regime. Principal mollusks of this unit include the brackish water species *Ampullinopsis crassatina* and *Neritina picta,* the rocky-substrate species *Tectarius elegans* (mediolittoral), *Anomia,* and *Thericium calculosum.* The top of this horizon contains a 25 cm thick *Strombus* (*Tricornis*) *sublatissimus* bed rich in pebbles and coral fragments and also containing the mollusks *Hipponyx, Astraea, Tectarius, Nassarius* and others. The proximity of the shore line is indicated by abundant and well preserved specimens of the typical mediolittoral-supralittoral tropical genus *Tectarius.* The disappearance of pebbles in the marls above the *Strombus sublatissimus* bed indicates a change to more tranquil conditions.

A preliminary comparison of the Pontonx (Mineur) and Estoti-Abbesses faunas shows that Miocene species are less important at Pontonx while typical Stampian species such as *Ampullinopsis crassatina* increase. These data agree with a study of *Miogypsinoides* by Cahuzac (1980) that placed the Pontonx strata as upper Oligocene but slightly older than at Estoti-Abbesses. Muller and Pujol (1979) studied the planktic foraminifers and calcareous nannoplankton at Pontonx in strata below that discussed in this paper and placed the strata (sample GA 29777) as NP 25.

Lower Miocene of the Adour Basin (Moulin de Carreau)

The lower part of the outcrop at Moulin de Carreau is a limestone that contains a fresh water fauna with some brackish water influence. Above and lateral to this limestone is a 2-meter thick succession of steel blue marls with thin layers of limestone. The most abundant species in this interval are the gastropods *Tympanotonos tournoueri* and *Granulolabium plicatum.* Living representatives of these taxa are quite common in lagoons and mud-flats at the mediolittoral position in West Africa (*Tympanotonos*) and Australia (*Granulolabium*). Thus these marls were probably deposited in a shallow lagoon with a maximum depth of 1 meter. Overlying these sediments is a 10-meter thick sequence of very fossiliferous (shelly), coarse sand with cross-bedding and shell lenses that indicate the presence of tidal currents. The rich fauna of this sequence is indicative of the lower beach environment in a tropical sea and includes bivalves of the families Mactridae, Arcidae, Ludinidae, Veneridae, and others, the gastropod families Trochidae, Rissoidae, Cerithiidae, Naticidae, Cypraeidae, Muricidae, Melongeniidae, and others, and fragments of corals. This fauna is followed by a reinstatement of lagoonal communities (marls with *Melongena lainei*).

Formerly thought to be lower Miocene (Aquitanian), a study of *Miogypsinoides* at Moulin de Carreau by Drooger (1958) indicated a lower Burdigalian age. Nevertheless, molluscan data (Degrange-Touzin, 1912) suggest that this fauna is slightly older than the classic Burdigalian of the northern Aquitaine Basin. Odin (1982, p. 703) dated the Aquitanian-Burdigalian boundary at Soustons in the southern part of the Aquitaine Basin at 20.5 ± 1 MA. The biostratigraphic position of the glauconite sample dated by Odin is probably situated at about the same level as the Moulin de Carreau strata.

Stampian (lower Oligocene) of the Paris Basin (Morigny)

The Morigny-Jeurre Formation (7 meters in thickness) comprises the upper part of the lower Stampian (NP 23, Aubry, 1983) in the Paris Basin. In the basal part, the sands of Morigny are characterized by an abundance of the bivalve *Glycymeris obovata.* This *Glycymeris* layer predominantly contains suspension feeding bivalves including *Glycymeris obovata, Laevicardium tenuisulcatum,* and *Parvicardium scobinulum,* but also contains gastropods including the suspension feeders *Calyptraea striatella,* the predators *Polinices* and *Typhis,* and the scavenger *Keepingia gossardi.* This community corresponds exactly with the infralittoral climax biocoenosis of the fine well-sorted sand assemblage (Gitton et al., in press). These assemblages live below the lower limit of the upper clean sands assemblage to a depth of about 20 meters on hard, terrigenous, well-sorted, fine sand (Peres, 1982, p. 434).

The *Glycymeris*-layer community passes upward into an assemblage containing the bivalve *Divaricella* (*Paralucinella*) and the crustacean *Callianassa.* This same community presently lives in the upper infralittoral to mediolittoral zone, thus indicating a retreat of the lower Stampian Sea. Disconformably overlying the Morigny-Jeurre Formation is the Vauroux-Saint-Antoine Formation of the upper Stampian. According to the time scale of Curry and Odin (1982, p. 629, *in* Odin, ed.), the age of the Morigny-Jeurre Formation can be estimated at 32 MA.

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